14

A SIMPLE PHASE-METER FOR LABORATORY USE

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(*Received, January* 27, 1959)

ABSTRACT. A simple phase-meter for ordinary use in a laboratory is described in this article. The construction of this equipment is very simple and the accuracy of measurement is much better than that available with an oscilloscope. It needs no calibration and can be used over a wide range of frequency.

INTRODUCTION

Measurement of phase is quite often needed in a radio engineering laboratory not only for research studies, but also for day-to-day practical work. In experiments on amplifiers, filters etc., it is often necessary to study their phase-response over the frequency range of interest. The ordinary method of phase measurement with an oscilloscope is inaccurate and inconvenient as it is basically a graphical method. Mainly for this reason phase-response of such systems is not always measured for ordinary purposes.

In the simple method of phase measurement described below, the accuracy of measurement is much higher than the ordinary oscilloscope method, and, in addition, it is a very convenient one. The accuracy is of course not as high as the other described earlier by the present author (1957), but it is sufficiently good for ordinary works. The equipment is very simple and can be readily constructed. The same instrument, without any modification, can be used for measuring phase changes in almost all types of electronic systems, covering a very wide range of frequency and signal amplitude. It is hoped to be found useful for measuring phase characteristics of different systems and their variations with frequency.

DESCRIPTION OF THE EQUIPMENT

The phase measuring equipment consists simply of two cathode-followers having a common cathode load as shown in figure 1. The two signals, whose phase difference is to be measured, are applied to the grids of the two tubes through switches as shown. The output of the cathode follower is measured with an a.c. vacuum tube voltmeter. Inputs are fed to both the grids through high resistance (of the order of megohms) potentiometers or some sush device for adjusting the levels of input signals to the respective grids.

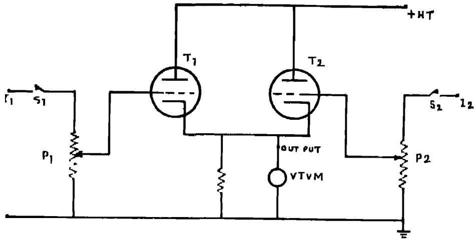

Fig. 1. A schematic circuit diagram of the phase-meter

In order to measure the phase difference between two signals, they are applied to the input terminals I_1 and I_2 (figure 1) respectively. Then the switch S_1 is closed, allowing the input at I_1 to be applied to the grid of the tube T_1. S_2 is kept open. The potentiometer P_1 is next adjusted to get a convenient reading (V) across the cathode follower output. Then S_1 is opened and S_2 is closed, allowing the input at I_2 to be applied to the grid of T_2. The potentiometer P_2 is adjusted to get the same voltage reading (V) across the output. Then S_1 is also closed and with both the inputs applied simultaneously, the output voltage (V_0) is measured. It is evident that this output (V_0) is the vector sum of the two inputs (V) which were made to be of equal magnitude.

Thus, $V_o = 2V \cos\frac{\theta}{2}$ (from figure 2), where θ is the phase difference between the two inputs. [For θ approaching 180°, V_0 may be so small that it may not be possible to measure it in the same scale of the voltmeter as used for measuring V, and a lower voltage scale has to be used. In that case, it is advisable to compare the readings in these two scales and make necessary corrections for discrepancies if any].

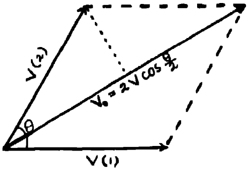

Fig. 2. Illustrating the vector addition of voltages at the output

As V and V_0 are known quantities, we can calculate $\cos\frac{\theta}{2}$ and hence θ. Also, as the same voltmeter (in the same range or in two ranges which are compared with each other and discrepancies corrected for) is used for measuring both V and V_0 and only their ratio is taken for calculating θ, any inaccuracy in the voltmeter itself is eliminated.

It is evident that V_0 will vary from $2V$ to 0 as $\cos\frac{\theta}{2}$ varies from 1 to 0 (the limits of its variations) *i,e*, θ varies from 0 to 180°—positive or negative. As the cosine of an angle is independent of its sign, no information is obtained regarding the sign of the phase angle. This is also not needed in most cases as the sign (*i.e.* relative lead or lag) of the phase angle is normally known beforehand.

RESULTS

To determine the accuracy of measurement of the instrument voltages having known phase shifts (introduced by standard circuit components) were applied to the two input terminals of the above meter and the phase measurements were made at different frequencies, as described in section 2. Known phase shifts were introduced by a combination of a standard condenser (of $0.01\mu F$) and a standard resistance (of $1K\Omega$) as shown in figure 3(a) and the voltages between terminals (1) and (2) were applied to the phase-meter for the measurement of phase shift produced. The measurements were carried out at different frequencies from 100 c/s to 20 Kc/s. The theoretically calculated values of phase-shifts produced by the above *R-C* combination of figure 3(a) at different frequencies were plotted and the curve in figure 3(b) shows this calculated variation of phase with frequency. The observed values of phase-shifts at different frequencies, as were experimentally measured by our phase-meter, were shown as circles on the same graph. A good agreement is observed between the calculated and measured values.

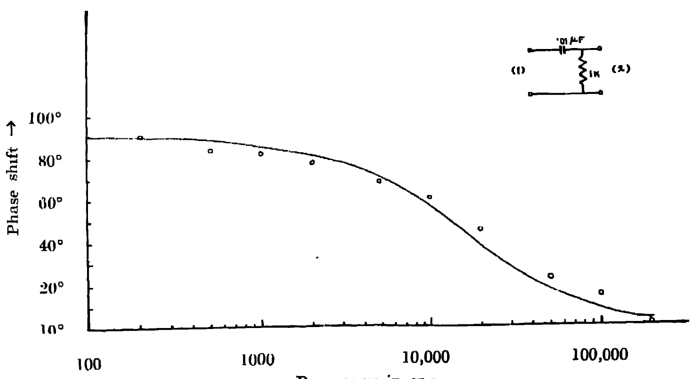

Fig. 3(a)

Fig. 3(a). R-C network with standard components for producing known phase-shifts.

Fig. 3(b). Variation of phase with frequency in the above network. The smooth line gives the calculated values and the circles indicated the values as measured with the given phase-meter.

Measurements were also carried out on phase-shifts produced by (1) a low frequency amplifier (untuned) and (2) a high frequency amplifier (tuned). The phase-shifts ϕ produced between the inputs and the output of an *R-C* coupled amplifier at different frequencies were measured and the relative phase-shift $\theta[|\theta| = 180^\circ - |\phi|]$ of the output voltage at different frequencies, with respect to the mid-frequency phase, are plotted in figure 4. The calculated values of phase-shifts at different frequencies are also shown dotted on the same graph. A good agreement is observed. But the agreement between the calculated and measured values in this case (as also in figure 5) is not as good as in figure 3.

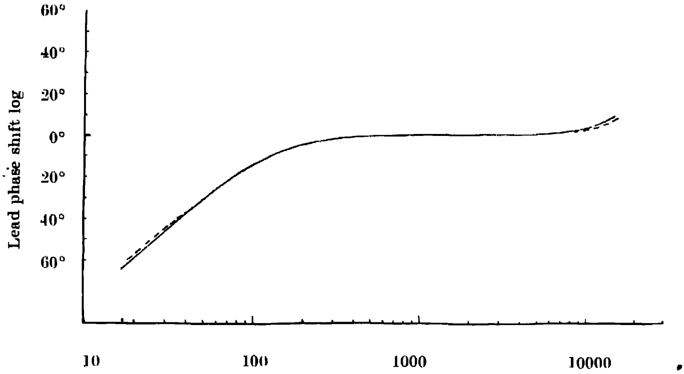

Fig 4 Variation of phase with frequency of an R-C coupled amplifier, as measured with the given phase-meter. The dotted line shows the calculated values.

Figure 5 shows a similar measurement in a single-tuned amplifier[1] with its tuning frequency at 440Kc/s. The observed results of phase-shifts with frequency are shown by the full line curve and the dotted line shows the calculated values. Here also, a more or less good agreement is observed As the values of the components used in this (as also the *R-C* coupled amplifier) are not known with so high precision as that for the standard components (in figure 3), the calculated values of phase-shifts are themselves not accurate. Hence, a larger discrepancy between the calculated and observed values is also expected.

DISCUSSIONS

By selecting a proper range for the V.T.V.M. and adjusting the potentiometers, the output voltage V (for a single input) may be made equal to half the full-scale reading. In that case the V.T.V.M. reading will be proportional to $\cos\frac{\theta}{2}$. As the scale of a V.T.V.M. (like that of Philips type GM6017) meter has normally about 100 divisions or more the accuracy of measurement of $\cos\frac{\theta}{2}$ becomes of the order of 1 in 100. This makes the accuracy of phase measurement of an order of

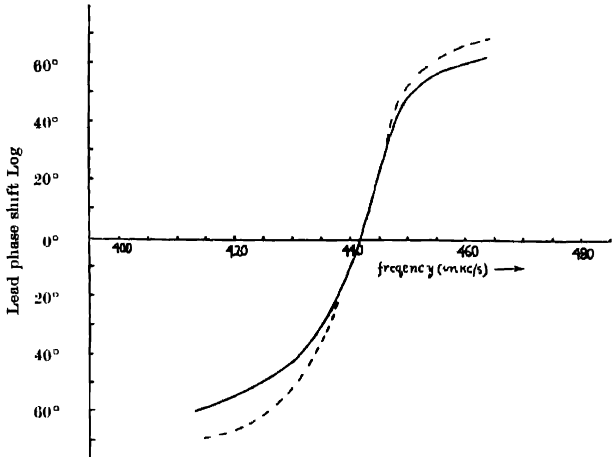

Fig. 5. Variation of phase with frequency of a single tuned voltage amplifier, as measured with the given phase-meter. The dotted line shows the calculated values.

about 2° and this is much better than that available with an oscilloscope. As $\cos\frac{\theta}{2}$ is not a linear function of θ, the accuracy of measurement will of course differ with different values of θ. But it is approximately about 2° except for very small values of θ The accuracy will be somewhat less for θ approaching zero degree, as in that case $\cos(\theta/2)$ changes vary little with θ.

As the instrument uses only cathode followers with resistive load, it can work satisfactorily over a wide range of frequency. With porper choice of tubes and circuitry, accurate results can be obtained from a few cycles per sec. up to a high frequency in the hundred megacycles range. The accuracy is not lowered even if the cathode follower gain falls somewhat at higher frequency. As the same V.T.V.M. is used to measure both V_0 and V, their ratio $\left(2\cos\frac{\theta}{2}\right)$ remains unaffected even if the cathode follower gain falls much below unity. It also gives linear operation over a large range of input voltage.

The major source of error at high frequency is the stray shunt capacitance across the input and output circuits of the cathode follower which cause undesirable (and unknown) phase changes. This is more important at the input end, where, to prevent loading of the circuit under test, a high resistance potentiometer is used. As the potentiometer settings for the two inputs generally differ, different amounts of phase-shifts will be introduced in the two signal inputs and the measurement will be in error. To prevent such errors caused by unequal phase shifts introduced at the two input terminals, specially when the two signal intensities differ much in amplitude, an arrangement similar to that in figure 6 may be used. The signal having the larger amplitude is passed through a cathode follower having a variable load resistance (R_K) and its amplitude at the phase meter input terminal I_1 is made to be equal to that of the other signal by varying R_K. As R_K is small, the effect of shunt capacitance across R_K can be neglected. Also, as both the signals are fed to the same resistor R_g, the phase-shifts produced by them (R_g) are equal and the relative phase difference between the two signals remain unchanged at the phase meter tube grids. As such no error is introduced.

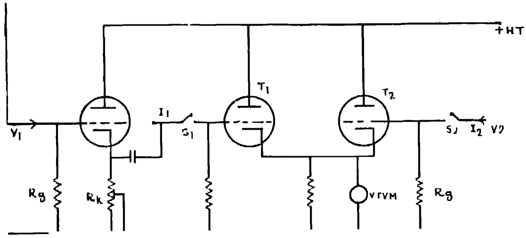

Fig. 6. A modified version of figure 1 for measuring phase at high frequencies.

As the measurement of phase needs a voltage measurement across the cathode follower output terminals (which is of low impedance), a voltmeter of ordinary design whose input impedance need not be high, may be used for this purpose.

In the ideal case, both the tubes T_1 and T_2 should be identical having the same values of r_p and g_m. For this purpose, it is preferable to use two triode tubes whose parameters have been found to be identical, as it is very difficult to find a twin-triode the two halves of which are identical. Of course, the condition of having identical parameters for both the tubes is not a stringent one, because the stage gain of a cathode follower is not much dependent on the tube parameters.

As mentioned earlier, the meter reading will be independent of the sign of phase change *i.e.* the meter will not indicate which voltage is leading or lagging. Thus, we should have a previous knowledge of the sign of phase change produced, which, of course, is known in most cases.

ACKNOWLEDGMENTS

The author is indebted to Prof. H. Rakshit, D.Sc., F.N.I., F.Inst.P., for his guidance, helpful suggestions and active interest in the work.

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